An economic analysis of a methionine source comparison response model

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ABSTRACT Methionine is the first-limiting amino acid in corn and soybean meal-based poultry diets. Therefore, its supplementation level is of primary economic importance to poultry production. The responses to the methionine sources dl-methionine (DLM) and methionine-hydroxy analog-free acid (HMTBA) have been compared using various methodologies. The so-called common plateau nonlinear model has been used to estimate relative bioavailabilities of the sources. This model has a coefficient that is used as a single value to compare the relative bioavailabilities of the sources for independent technical parameters like gain and feed efficiency. This model was used previously in a meta-analysis of published experiments, and 79 and 81% relative biological efficiencies of HMTBA were found for DLM for ADG and feed utilization efficiency, respectively. Because different sources would have different optimal feeding levels to maximize profits, we demonstrate the challenge of calculating a single optimal level for the different methionine sources. Further, we apply an economic analysis to results of the previous meta-analysis to demonstrate that the relative values of HMTBA and DLM for BW and ADG are between 81 and 86%, depending on the value of a broiler and the costs of feed and DLM.

Key words: methionine, biological efficiency, economic efficiency

INTRODUCTION

Noll et al. (1984) proposed a model to estimate the relative bioavailability of nutrients based on an exponential, common plateau model with a parameter that was said to be the relative bioavailability (the $\varepsilon^{-1}$ coefficient). Littell et al. (1997) demonstrated how to fit the model to experimental data using SAS (SAS Institute, 1989). The Noll et al. (1984) model was used by Sauer et al. (2008) in a meta-analysis of experiments on the relative efficiency of 2 potential sources of methionine for broilers. The methionine sources they compared were dl-methionine (DLM) and methionine-hydroxy analog-free acid (HMTBA). The meta-analysis included an estimation from a single model using data from 42 experiments in 27 published papers. The exponential model used was:

$$y = \alpha - \beta \exp(-\gamma x), \quad [1]$$

where $x$ is the dose in percentage of supplemental methionine source and $\alpha$, $\beta$, and $\gamma$ are constants. Sauer et al. (2008) allowed for a difference in plateaus from the 2 methionine sources but concluded that the difference was not statistically significant. Therefore, they used the models estimated in the meta-analysis experiment to calculate the relative bioavailability of HMTBA to DLM at the plateau level. The latter was then used to price HMTBA relative to DLM.

However, this approach is flawed from the economic perspective because it implicitly assumes that there is a single relative value of the sources, regardless of the cost of feed components and the price of live birds. The coefficients used to compare levels of supplement to feed are determined without regard to any prices whatsoever. In fact, given a nonlinear response model, it is impossible to have a single coefficient that represents the relative value of methionine sources (or other supplements) under more than one unique set of technical and economic conditions at a time. The inadequacy of the Noll et al. (1984) model can best be illustrated by the following stylized model of economically optimal feeding.

Assume that a bird is fed a standard feed and a supplement. The live weight ($w_l$) of a bird at slaughter is a function of the quantities of feed ($q_f$) and supplement ($q_s$) [i.e., $w_l = w_l (q_f, q_s)$]. If the per-unit costs of feed and supplement ($c_f$ and $c_s$, respectively) are constant, and so is the per-pound price of live bird ($p$), then the net profit per bird is

$$\pi = pw_l(q_f, q_s) - c_f q_f - c_s q_s. \quad [2]$$
The economically optimal level of the supplement is then determined by taking a derivative of \[2\] with respect to \(q_s\) and setting it to zero so that

\[
\frac{\partial \pi}{\partial q_s} = p \frac{\partial w_i}{\partial q_s} - c_s = 0
\]

(see, for example Mas-Colell et al., 1995, p. 137). An economic interpretation of this condition is that the supplement is fed up to the level when the additional revenue of the live weight gained from one additional unit of supplement is equal to the cost of that additional unit. A similar result would be obtained even if parts of the carcass were priced differently, as long as the weights of the parts remained in a constant proportion to the live weight. The condition can be rewritten as an equation on the optimal quantity of the supplement:

\[
\frac{\partial w_i(q_f, q_s^*)}{\partial q_s} = \frac{c_s}{p} \tag{3}
\]

Graphically, the rule in \(3\) implies that, at the optimum, the slope of the tangent to the nutrient response curve is equal to the ratio of the nutrient’s cost and the price of live bird per unit of weight.

Generally speaking, different nutrient sources would result both in different response functions \(w_i = w_i(q_f, q_s)\) and the ratio of the nutrient’s cost to the price of live bird. As a consequence, economically optimal levels of various nutrients as determined by \(3\) might be incomparable. Figure 1 demonstrates this point by a typified example of feed response curves for 2 sources of a supplement (or a nutrient). The example shows 2 different combinations of response curves and prices of supplements that result in 2 different economically optimal quantities of the supplements. Here, \(c_s^1\) and \(c_s^2\) are per-unit costs of 2 supplements, \(p\) is the per-unit price of live bird, and \(q_s^1\) and \(q_s^2\) are economically optimal quantities of 2 supplements implied by the condition in \(3\).

This example demonstrates the challenge of calculating a single optimal level of supplement sources or the degree of relative substitutability between 2 sources because these different sources would have different optimal levels. However, a direct comparison of the supplement sources in this context is still possible (e.g., by selecting the source that provides the highest profit at the optimum response). One possible approach to such a comparison is to find the cost of one source which, at optimum, results in the same live weight as another source. This approach is illustrated in a stylized example shown in Figure 2.

In Figure 2, the price of supplement 1 \((c_{1eq}^*)\) is chosen so that the corresponding optimal level of the supplement \((q_1^*)\) determined according to \(3\) results in the same live weight \(w^*\) as the optimal level of supplement 2. In this context, the price of the first source \((c_{1eq}^*\) is indeed equivalent to the price of the second source \((c_{2eq}^*\).

However, this equivalence would only hold at the optimum and only as long as all of the other parameters are

![Figure 1](image1.png)

**Figure 1.** Economically optimal supplement levels for different combinations of response functions and supplement prices. \(c_s^1\) and \(c_s^2\) are per-unit costs of 2 supplements, \(p\) is the per-unit price of live bird, and \(q_s^1\) and \(q_s^2\) are economically optimal quantities of 2 supplements implied by the condition in \(3\).
fixed. In other words, if, for example, the price of a live bird were to change, the slopes of tangents in Figure 2 would change and the equivalence would disappear because each source of nutrient would now have optimal quantities resulting in different optimal weights. Similarly, a change in other components of the diet might change the curvature of the response function and once again break the equivalence. Finally, a choice of the live weight for comparison is completely arbitrary (i.e., different objective functions would result in different implied relative costs of the nutrient sources). In fact, although the optimal quantities in the example shown in Figure 2 yield the same weight, they would most likely result in different net profits.

Despite that the $\varepsilon^{-1}$ coefficient of Noll et al. (1984) and Sauer et al. (2008) is inadequate for determining the relative economic values of DLM and HMTBA, an economic interpretation of the regression model is still valuable in demonstrating how the relative values of DLM and HMTBA change with changing prices of inputs (feed) and outputs (live weight).

**MATERIALS AND METHODS**

Note that there are errors in the published signs of the $\beta$ coefficients in the equations in Sauer et al. (2008). Therefore, the actual equations used in the present analysis were as follows:

$$ADG_{DLM} = (32.83 + 1.03 \times ASE) - 10.46 \times \exp(-13.58 - doseDLM)$$

and

$$G:F_{DLM} = (0.52 - 0.0026 \times ASE) - 0.12 \times \exp(-8.41 \times doseDLM)$$

where $ASE$ is age at start of experiment and $doseDLM$ and $doseHMTBA$ are the amounts of the respective methionine sources (Figures 3 and 4).

For a given choice of the methionine source, the model in [2] can now be written either as

$$\max \pi = p \cdot N \cdot ADG_{DLM}(ASE, doseDLM) \cdot G:F_{DLM}(ASE, doseDLM)$$

or

$$\max \pi = p \cdot N \cdot ADG_{GMTBA}(ASE, doseGMTBA) \cdot G:F_{GMTBA}(ASE, doseGMTBA)$$

Figure 2. An equivalent price of a supplement determined so as to produce the same optimal live weight. DLM = dl-methionine; HMTBA = methionine-hydroxy analog-free acid.
where $N$ is the number of days the bird is fed; $p$, $c_s$, and $c_f$ are the same as in [2]; $dose_{DLM}$, $ADG_{DLM}$, and $G:F_{DLM}$ are as defined in [4a] and [5a], respectively; and $dose_{HMTBA}$, $ADG_{HMTBA}$, and $G:F_{HMTBA}$ are as defined in [4b] and [5b], respectively.

The maximization problems in [6a] and [6b] were solved for several combinations of supplement and live bird prices (scenarios) listed in Table 1. Scenario 1 contains average prices for the very volatile autumn of 2008, whereas other scenarios represent a range of historical highs and lows for the basal diet cost, live broiler value, and DLM cost to illustrate extreme combinations of these factors. The profit-maximizing dose of DLM was determined using the Solver module in

**Figure 3.** Mean values of the dose-response relationship between DL-methionine (DLM) and methionine-hydroxy analog-free acid (HMTBA) with ADG on an equimolar basis based on the common plateau covariate model of Noll et al. (1984). Age at the start of the experiment was 10 d.

**Figure 4.** Mean values of the dose-response relationship between DL-methionine (DLM) and methionine-hydroxy analog-free acid (HMTBA) with G:F on an equimolar basis based on the common plateau covariate model of Noll et al. (1984). Age at the start of the experiment was 10 d.
Microsoft Excel (Microsoft Corp., Redmond, WA). The optimal levels of DLM for each scenario are reported in Table 1. After the procedure illustrated in Figure 2, the price of HMTBA was then varied so as to set the maximum profit based on the HMTBA response functions equal (within $0.0000005) to the maximum profit obtained in the case of DLM. The ratio of the costs of HMTBA to DLM that yielded identical profits were then calculated and also reported in Table 1.

RESULTS

The profit-maximizing doses of DLM and HMTBA computed in this paper were outside of the ranges of methionine sources fed in 38 of the 42 experiments that provided data to analysis by Sauer et al. (2008). As expected, when the cost of DLM increased, its use decreased and the relative values of HMTBA increased. Furthermore, when the cost of either the basal diet or live broilers increased, DLM and HMTBA usages on an absolute basis increased. The ratios of the values of DLM to HMTBA ranged from 80.5% with low feed and broiler prices and high DLM prices to 85.6% with high feed and live broiler prices and low DLM prices.

DISCUSSION

The model of Noll et al. (1984) has become known as the nonlinear common plateau regression model (Kratzer and Littell, 2006). This is surprising because the model has no plateau, and the only common point is where the values of the supplements are both equal to zero. With the model of Noll et al. (1984) and Little et al. (1997), the source with the lower initial response will necessarily always approach the plateau from below and never actually equal the response from the other source that has the higher initial response. Thus, although the data and theory support the common plateau idea, in the practical application of this exponential model, the responses never reach equality at any common plateau. The difference in approaches is not trivial, as evidenced by the different economic results in Table 1.

The only references to the model used by Noll et al. (1984) are to general reference articles on nonlinear regression, so we assume that the model should be attributed to them. In the Noll et al. (1984) model, the relative potency was the parameter they called the ratio of steepness coefficient. Noll et al. (1984) correctly state “These are the factors that, when multiplied by the corresponding levels, make the DL-methionine growth curve coincide with that of the other source.” That statement is true. However, it does not follow that the ratio of steepness coefficient can be used to determine appropriate relative prices of the nutrient sources without regard to costs of inputs (basal diets and supplements) and outputs (body or carcass weights) as is typically done.
Two separate observations strongly suggest that the exponential model is inadequate. First, most of the profit-maximizing DLM and HMTBA optimal dose supplemental levels were above 0.32%; the only exception was when both basal diet costs ($/kg) and live broiler values ($/kg) were at very low values and the DLM value was high (Table 1). However, only 4 of the 42 research trials included in the analysis of Sauer et al. (2008) fed DLM or HMTBA levels this high. Of the 38 experiments in which less than 0.32% DLM was fed, the average highest dose fed was 0.19% (Table 1 of Sauer et al., 2008). Second, none of the individual experiments included by Sauer et al. (2008) in their analysis showed significant differences between methionine sources when they were fed at the highest levels. Therefore, the plateaus were reached at an average of 0.19% supplement level in the majority of experiments included in the analysis. The maximum responses (plateaus) were clearly reached at 0.28% in 38 of the 42 experiments in the analyses of Sauer et al. (2008). The optimal dose

![Figure 5](image1.png)

**Figure 5.** Mean values of 28-d BW gains (g) in broiler chickens as reported by Schutte and de Jong (1996). A t-test revealed that the predicted plateau for methionine-hydroxy analog-free acid (HMTBA) was significantly higher than that for DL-methionine (DLM) ($P = 0.0014$), which demonstrates that the dose responses of the 2 products are different (Kratzer and Littell, 2006).

![Figure 6](image2.png)

**Figure 6.** Mean values of 28-d BW gains (g) in broiler chickens as reported by Schutte and de Jong (1996). Use of the nonlinear common plateau asymptotic regression model forces a common plateau for the 2 sources of methionine at 1,714 g (Kratzer and Littell, 2006). HMTBA = methionine-hydroxy analog-free acid; DLM = DL-methionine; b4 = ratio of rate estimates, the relative efficiency; CL = confidence limits.
(Table 1) was considerably (0.04 to 0.34%) above the supplement levels, where the plateau should have been reached, except when both basal diet cost ($/kg) and live broiler values ($/kg) were at very low values and the DLM value was high (Table 1). But even with very low diet and broiler values and high supplement values, the optimal doses of 0.26% DLM and 0.32% HMTBA were considerably above where the maximum response was reached in many of the experiments (0.19% DLM or HMTBA).

The process of determining relative ingredient prices is very important for animal nutrition and critical to economically producing food. Any proposed mathematical model should undergo careful scrutiny from the biological, statistical, and economic perspectives. Kratzer and Littell (2006) tested the hypothesis that the same maxima are approached by 2 methionine sources using the model of Noll et al. (1984). They concluded that, from a statistical perspective, the maxima (plateaus) for the 2 sources were different and, therefore, the biological principles involved should be reevaluated. The biological principles, of course, seem to indicate a common plateau for sources of the same nutrient. If there is no common plateau, it would seem that basic assumptions of the experiments, that methionine was the limiting nutrient in the diets and that the supplements were solely sources of methionine, were false.

Mathematical models should necessarily describe the observed biological processes. Extrapolations outside the observed points are by definition unsupported. Therefore, it is interesting to note that even for the example data that Kratzer and Littell (2006) chose to illustrate their point, the maximum (plateau) is clearly outside the range of the observed data (Figure 3); t-tests comparing responses to methionine sources at the highest level of substitution would have been much more convincing than t-tests comparing predicted plateaus.

When a statistical model suggests problems with biological theory, it may correctly suggest that the biological interpretation is inappropriate. In the case of methionine sources studied by Kratzer and Littell (2006), one possibility is that some property of HMTBA, other than its methionine activity, is increasing growth responses from its use (Figure 5). Methionine-hydroxy analog-free acid is known to have activity as an organic acid and may increase phytate phosphorus and trace mineral absorptions (Liem et al., 2008). For appropriate comparisons of HMTBA and DLM, experimental diets need to be formulated to only compare methionine activity. Any positive influence from any organic acid effect or other properties should be accounted for separately. If the difference in plateaus was due to d-methionine toxicity, there should be no plateau in the response to DLM.

Sauer et al. (2008) used the common plateau model to find 79 and 81% relative efficiencies (DLM vs. HMTBA) for ADG and feed utilization efficiency, respectively. It is difficult to interpret models with separate efficiencies for whatever parameters happen to be measured. The efficiency estimates for individual parameters may be interesting from a technical perspective. However, from an economic perspective, it is more important to find the relative values of the supplements in a model that includes the value of gain produced and cost of feed consumed (net profit, as in Table 1). In this case, the relative economic values (cost ratio, HMTBA:DLM) are between 81 and 86%. But again, because the profit-maximizing levels of DLM and HMTBA are so far above the levels studied in most of the experiments, the validity of any conclusions is highly suspect. This comparison was only made to illustrate how the data should be interpreted.

It does not seem reasonable that one nutrient source should always approach the maximum from an inferior position because of lack of response at very low levels (Figure 6) any more than there should be different maxima (plateaus; Figure 5). A mathematical expression capable of modeling a sigmoidal approach to a true plateau needs to be applied that biologists, statisticians, and economists can all consider adequate. The real relative values of nutrient sources need to be evaluated in terms of the complete feeds that are to be used to determine fair values. In that way, all positive and negative attributes and interactions can be accounted for. As illustrated in Table 1, relative economic values are dependent on the technical responses and costs of the inputs (like feed) and value of the outputs (like broiler meat). Therefore, models with only technical data should not be used to determine relative biological values that are to be used for determining relative prices.

**REFERENCES**


